United States Department of Agriculture
Agricultural Research Service
Soil and Water Conservation Research Division
Corn Belt Branch

NORTH APPALACHIAN EXPERIMENTAL WATERSHED

COSHOCTON, OHIO

ANNUAL REPORT FOR THE YEAR 1970

In cooperation with the Ohio Agricultural Research and
Development Center
Wooster, Ohio

Prepared by the Station Staff
(List on reverse side)

March 1, 1971

PERSONNEL

L. L. Harrold, Officer-in-Charge
F. W. Chichester, Research Soil Scientist (Chemistry) September 20, 1970
W. M. Edwards, Research Soil Scientist (Physics)
J. L. McGuinness, Research Statistician
T. C. Wei, Hydraulic Engineer, October 5, 1970

W. W. Bentz, Hydraulic Engineering Technician
H. E. Frank, Physical Science Technician
D. B. Wall, Engineering Technician
M. C. Young, Agricultural Research Technician (Soils)
T. E. King, Hydraulic Engineering Technician

M. A. Aronhalt, Statistical Clerk
G. R. Carruthers, Clerk
S. A. Cherry, Key punch operator (OARDC) Resigned 12-22-70
C. E. Duren, Clerk-Typist (OARDC, September 29, 1970)
L. H. Duren, Clerk-Typist (OARDC) Resigned 09-25-70
M. K. Royer, Statistical Clerk
C. A. Salrin, Computer Technician

K. E. White, Operations and Maintenance Lead Foreman
R. H. Cunningham, Automotive Mechanic

C. I. Olinger, Agricultural Research Technician
E. W. Burrier, Farm Equipment Operator
C. R. Huprich, Farm Equipment Operator

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INTRODUCTION

A. Summary of climate

Precipitation for the year, 37.07 inches (table 1), was almost exactly the normal of 37.10 inches. Above normal precipitation in April resulted in significant runoff (table 1) while the above normal precipitation following the very dry August resulted in lesser amounts of streamflow. Only three excess storms were recorded on June 17, July 29, and September 3. Peak rates of runoff on the complex watersheds occurred in January and April. That in April on the 303-acre watershed was 0.52 inch per hour, ranking 11th in order of magnitude in the 34-year record. Of the highest 13 floods, 9 occurred in the growing season and 4 in the winter-spring season.

Table 1.-Precipitation and runoff summary, 1970

Month	Precipitation		Runoff				
			Corn	Pasture	Mixed cover		
	Normal	1970	1.7 Ac. (109)	1.6 Ac. (130)	79 Ac. (166)	303 Ac. (196)	4,580 Ac. (97)
	In.	In.	In.	In.	In.	In.	In.
Jan.	2.83	2.46	0.19	0.43	1.54	1.89	1.52
Feb.	2.23	1.76	0	0	1.58	1.87	1.67
Mar.	3.42	3.42	0	0	1.66	1.96	1.63
Apr.	3.54	5.79	.01	.81	3.75	4.53	4.17
May	3.88	3.67	0	0	.70	1.07	1.26
June	4.35	3.52	0	0	.22	.38	.28
July	4.58	3.36	.01	0	.08	.18	.14
Aug.	2.77	.49	0	0	.01	.07	.01
Sept.	2.58	3.72	0	0	.03	.12	.06
Oct.	2.21	3.56	0	0	.13	.22	.18
Nov.	2.44	2.86	0	0	.50	.72	.64
Dec.	2.27	2.46	0	0	1.35	1.66	1.26
Year	37.10	37.07	.21	1.24	11.55	14.67	12.82

Average annual air temperature for 1970 was 50.3°F, about average for the 32-year period of record (table 2). Mean monthly temperatures for January, February, and March were below average, with January having a -7° departure. Coldest temperature was -8° in January . A minimum temperature of 28° in May, 1970 was unusual. The May-August period was warmer than average. Warmest temperature was 92° in June and July.

Table 2.-Monthly air temperature, 1970 (°F)

Month	Maximum	Minimum	Mean	Normal mean[1]	Number of days mean temperature was below freezing
Jan.	56	- 8	19.8	27.1	26
Feb.	54	- 4	27.9	28.9	19
Mar.	65	12	35.0	37.2	11
Apr.	84	24	51.8	49.2	--
May	86	28	63.1	59.4	--
June	92	48	69.0	68.5	--
July	92	49	72.8	72.4	--
Aug.	91	56	73.0	71.1	--
Sept.	90	38	64.0	64.2	--
Oct.	77	32	54.8	53.5	--
Nov.	64	11	40.9	40.6	5
Dec.	64	8	31.9	29.8	15
Year	--	--	50.3	50.2	76

1/ 32-year average 1938-69

The number of days and depth of frost penetration into meadow soil are shown in table 3, along with the 1940-69 averages.

Table 3.-Frost penetration in 1970 compared with 1940-69 period

Month	Number of days of frost				Maximum frost depth (inches)			
	Wheat		Meadow		Wheat		Meadow	
	1970[1]	Avg.[2]	1970[3]	Avg.[2]	1970[1]	Av.[2]	1970[3]	Avg.[2]
January	--	22	31	16	--	11.0	13.5	8.0
February	--	19	28	16	--	11.8	9.5	8.8
March	--	10	26	6	--	10.2	9.5	5.0
December	--	7	19	8	--	8.7	2.0	7.3
Total	--	58	104	46	--	--	--	--

1/ Not measured.
2/ For period 1940-69.
3/ Frost measured at index plot by penetrometer.

The largest snowfall occurred on March 13 with a depth of 3.0 inches (table 4).

Table 4.-Snowfall in 1970 compared with 1940-69 averages

Month	Total inches snowfall		Total days of snow cover	
	1970	Average	1970	Average
	Inches	Inches		
January	6.5	7.4	28	13
February	2.5	6.8	9	11
March	5.5	3.7	11	6
December	5.0	6.2	6	10
Total	19.5	24.1	54	40

B. Crops

Rainfall through July was adequate to meet crop needs. Although August rainfall was only 0.49 inch (2.35 inches below average) crops obtained enough water from soil-water storage to carry them over to harvest time. Corn yield on all watersheds was over 100 bushels per acre. Average yield on seven no-tillage watersheds was 124 bushels per acre and, on two under conventional tillage, 122 bushels per acre. Hay yields on improved-practice watersheds averaged 3.88 tons per acre and on unimproved, 2.18 tons per acre.

Corn yield on conventional-tilled lysimeter was 136 bushels per acre and on no-tilled lysimeter, 135. Crop use efficiency was 6.1 bushels per acre per inch of water used by conventional methods and 7.1 bushels per acre per inch of water by no-tillage methods. Mulch on the latter saved 3.36 inches of soil water evaporation and likely accounted for greater crop yield and 16 percent increase in crop water use efficiency.

C. Changes in personnel

Mr. F. J. Dragoun, Research Hydraulic Engineer, resigned May 15, 1970.

Dr. F. W. Chichester, Research Soil Scientist (Chemistry) transferred from the U. S. Soils Laboratory to Coshocton, Ohio September 20, 1970.

Mrs. Lorna H. Duren, Clerk-Typist, OARDC, resigned September 25, 1970.

Mrs. Carol E. Duren, Clerk-Typist, OARDC, employed September 29, 1970.

Dr. Tsong C. Wei was appointed Hydraulic Engineer, October 5, 1970.

Mrs. Shirley A. Cherry, Keypunch operator, OARDC, resigned December 22, 1970.

Mr. David J. Gilmore, OSU student assisted in field data collection during the summer quarter and Christmas holidays.

Mr. Robert B. Clark, Muskingum Area Technical Institute student, assisted in the soil laboratory during the summer quarter.

The services of five girls and three boys, high school age, were obtained through the Neighborhood Youth Corps (NYC) program during the summer months. They were trained in office and field duties and contributed notably to the research activities.

D. Activities contributing to public awareness of research

Visitors to the Station in 1970 totaled 1,443 of which 63 were from foreign countries, (Australia, Bulgaria, Canada, Denmark, England, Netherlands, India, Ireland, Japan, Nigeria, and Poland), 1,244 came in 30 tours, and 49 individuals from 14 states.

Staff members of the North Appalachian Experiment Station supplied research information to the public on numerous occasions.

			Number of people
February	12	Advisory Committee, Water Pollution Control Area, Muskingum Techinal Institute	15
March	4	SCS Area personnel	16
	4	Kiwanis Club, Coshocton	85
	7	Kent State University, New Philadelphia Branch	35
	11	WLWC-TV Columbus, story of research at Coshocton	5000
	25	Highland County SWCD Annual Meeting	80
April	2-3	Cornell University graduate students	9
	9	State Conservationists, SCS	3
	15	Marietta College environmental studies group	70
	17	Ohio Academy of Science annual meeting	110

			Number of people
April	18	Talmadge Ohio Methodists	40
	22	Zanesville Conservation students	13
	29	Ohio State University conservation classes	130
	29	Akron University ecology teachers	15
May	6	Wayne County Vocational School	10
	7	Coshocton Middle School	150
	11	Muskingum Vocational Technical Institute, pollution studies	40
	16	Kent State University graduate students	17
	17	Bulgarian Soil Scientists	8
	19	Warsaw Lions Club	50
	21	Denison University, environmental biology class	20
June	2	Agricultural Extension Specialists	12
	15	Ohio Agricultural Research and Development Center, Agricultural Engineering scientists	30
	17	Malone College ecology teachers	15
	27	Children from Cleveland Ghetto and Coshocton host families	80
July	6	Delaware Univ. geography teachers class	26
	10	Ohio Department of Agriculture, Pest Control	50
	15	Kent State University conservation teachers	42
	20	Union County FFA	29
	24	Ohio State University graduate students	6
	31	4-H boys and girls, all Ohio	225
August	3	SWCD Supervisors Workshop, Marietta College	300
	7	Ohio State University geology students	30

			Number of people
August	11	Ohio State University, agricultural engineering	15
	11	Plainfield 4-H	15
	14	OARDC Dairy Day	300
	19	West Lafayette Rotary	25
	24	Kent State University geographers	45
	26	WLWC-TV story of research at Coshocton station	5000
	26	Licking County SWCD cooperating farmers	16
September	7	University of Guelph, Ontario, Canada students	40
	23	Coshocton Lions Club	60
	28	Muskingum Technical Institute	85
October	8	Denison University NSF environmental science students	83
	15	Farmers field day, Holmes County	100
	21	Lansing Michigan Great Lakes pollution AD Hoc Committee	25
	23	OARDC Region III soil judging contestants	40
	24	Ohio State University Soil Erosion Class	24
	24	Ohio State University agricultural engineers	33
November	12	Champaign County SWCD Annual Meeting	300
	18	Carrollton, Ohio Corn Club Banquet	200
	19	Ohio State University Conservation Classes	110
December	4	Coshocton High School Community orientation	50
	14	St. Clairsville, Ohio Rotary Club	65
			13,392

E. Cooperative research with ARS-SWC

Studies by the U. S. Hydrograph Laboratory and U. S. Soils Laboratory at Beltsville, Maryland and Northeast Watershed Research Center at University Park, Pennsylvania were continued cooperatively at Coshocton as follows:

a. Application of physical and hydrologic data from Coshocton watersheds was made to develop numerical factors for the U. S. Hydrograph Laboratory watershed model.

b. Potential evapotranspiration frequencies techniques were developed in cooperation with the Northeast Watershed Research Center.

c. Pollution of soil, water, and air was studied in cooperation with the U. S. Soils Laboratory, Beltsville.

F. Cooperation with universities

1. Three master of science candidates in civil engineering, The Ohio State University, worked out their thesis problems on Coshocton Station data.

   a. S. Owen, "Modification of the Stanford Watershed Model IV to Improve Ground-Water Simulation in Stratified Geologic Regions," completed.

   b. W. Mease, "A Snowmelt Subroutine for Streamflow Simulation in Ohio," completed.

   c. L. Valentine, "Modification of the Stanford Streamflow Simulation Model IV for the Analysis of Small Watersheds," completed.

   d. J. Warns, "Users Manual for the O.S.U. Version of the Stanford Streamflow Simulation Model IV," in progress.

2. Dr. Brian Reich and graduate student studies at Penn State University used flood peak data from the Coshocton Station along with data from other locations to improve flood peak prediction for basins less than 30 mi^2 area in Ohio.

3. Dr. Eric Bordne, Geography Department, Kent State University, Kent, Ohio, cooperated with J. L. McGuinness, station statistician, to compare estimates of potential evapotranspiration using various prediction formulations with those from the Coshocton lysimeter.

4. Lynn Hamilton, a graduate student in the Geography Department, Kent State University, mapped out potential soil sampling sites where old hardwoods, pines, locusts, idle land, and pasture could be compared on several soil types.

G. Cooperative herbicide studies with OARDC.

Preliminary studies of the fate of atrazine and simazine in soil and water systems were made on conventional and no-tillage corn watersheds and lysimeters. These herbicides are used normally on cornland to control weeds. Samples were taken by the Coshocton staff and analyzed by OARDC.

H. Study of movement of agrichemicals

With the transfer of Dr. F. W. Chichester to the Coshocton Station in September 1970, a much greater portion of the research effort will be placed on movement of agrichemicals into surface and subsurface water bodies and adsorption on sediments and transport thereby. The laboratory is being renovated and equipped to perform chemical and physical analyses of water and soil samples currently as the samples are obtained. Field watershed studies are being planned to apply fertilizer at different rates and times, to evaluate its movement related to climate, water flux, land use, and physical characteristics of the flow system. Dr. T. C. Wei will collaborate in the development of mathematical predictive models of the flux of chemicals through the watershed system.

A. <u>CRIS WORK UNIT</u>: SWC-011 cCos-1

<u>Research outline</u>: A study of the areal distribution characteristics of severe local storms in northeast Ohio, Cos-68-11.

B. <u>LOCATION</u>: Coshocton, Ohio

C. <u>PERSONNEL</u>: <u>J. L. McGuinness</u>, L. L. Harrold, W. M. Edwards, F. W. Chichester, and T. C. Wei; cooperators: Grant Vaughan, U. S. Weather Bureau, Akron-Canton Airport, and Ohio Agricultural Research and Development Center.

D. <u>DATE OF PLANNED TERMINATION</u>: 1973

E. <u>OBJECTIVES</u>: 1. To determine the depth-area relations of local severe rainstorms in northeast Ohio.

2. To determine the duration, frequency, and other characteristics of these storms and the resulting runoff and damages.

F. <u>NEED FOR STUDY</u>: The most damaging upland flooding occurs in the growing season as a result of local, severe rains. A dense network of gages covering a large area is required to adequately define the isohyetal pattern of these storms.

G. <u>PROCEDURE</u>: Over 1,600 volunteer rainfall observers are functioning during the April through October season in a 1,500 square mile, 4-county area north of the Station. Upon request, these observers furnish reports on local, severe storm rainfall. These reports are supplemented by radar pictures of the storm taken at the Akron-Canton Airport Weather Bureau Office and an isohyetal map is produced. These maps contain the basic data for the depth-area-duration-frequency studies as stated in the objectives.

H. <u>EXPERIMENTAL DATA AND OBSERVATIONS</u>:

<u>The network</u>: The number of volunteer rainfall observers remained at 1,569 from January 1 to the end of 1970. Observer response to our requests for storm information remained quite satisfactory. No major problems were encountered in network operation during the year.

Detailed information on rainfall was collected for the storms of May 12, June 12, and June 15. Rainfall amounts for the May 12 event were quite high, averaging about 1.5 inches over the area. However, the amounts were very uniform and the storm

pattern was too vague to define believable isohyets. A maximum reading of 3.3 inches in 24 hours was made during this event in southwest Wayne County. The storm of June 12 was generally limited to the eastern part of Wayne County. The details of this event are given below.

Heavy rains were experienced over the network on June 15 and 16. The first burst of rain fell during the morning of June 15, a second heavy rain fell that evening, and a third storm occurred on the morning of June 16. With the staggered reading times used by the observers, some information was available on each storm but not enough to warrant preparing isohyetal maps. In addition each storm extended beyond the north or east boundary of the network making the closing of isolines difficult. Readings of 3.8 inches in one hour and 4.5 inches in 6 hours were recorded in northern Wayne County while totals over 7 inches in slightly more than 24 hours were listed along the northern border of the network.

Outstanding rainfall amounts during the season are tabulated in table 11.1.

Table 11.1.-Outstanding storms during 1970.

Date	Highest amount reported inches	Duration	Location	
			Town	County
4-1 & 2	2.9	12	Millersburg	Holmes
4-23 & 24	2.1	10	Uhrichsville	Tuscarawas
5-12	3.3	24	Shreve	Wayne
5-24	2.5	24	Dover	Tuscarawas
6-5	3.7*	1	Strasburg	Tuscarawas
6-12	3.5*	3	Orrville	Wayne
6-15 & 16	3.8*	1	Marshallville	Wayne
	4.5*	6	Smithville	Wayne
6-26	2.8	11	Navarre	Stark
7-8 & 9	3.4	24	Smithville	Wayne
7-10 & 11	2.1	24	Creston	Wayne
7-23	2.1	15	Orrville	Wayne
7-29	3.8	13	Rittman	Wayne
8-13	3.0*	2	Burbank	Wayne
8-18	2.5	6	No. Lawrence	Stark
10-12	2.3	17	Smithville	Wayne

* Indicates 100-year point rainfall event by USWB Tech. Paper 29 criterion.

<u>Storm of July 12, 1970</u>: Isolated thunderstorm activity occurred in northeast Ohio during the afternoon of June 12 in advance of a cold front coming into the state from the north. The storm for which the isohyetal map is given in figure 11.1 occurred during a three-hour period from 1500 to 1800 hours. The 3.5 inches recorded during the three-hour period near the center of the storm in Orrville is a 100-year point rainfall, table 11.1.

I. <u>COMMENTS AND INTERPRETATIONS</u>: The depth-area relations for the June 12 event is given in figure 11.2. The fit of the theoretical points (computed using bivariate normal theory) to the measured curve is good.

Five of the storms listed in table 11.1 have at least a 100-year return period according to the point rainfall criteria of USWB Technical Paper 29.

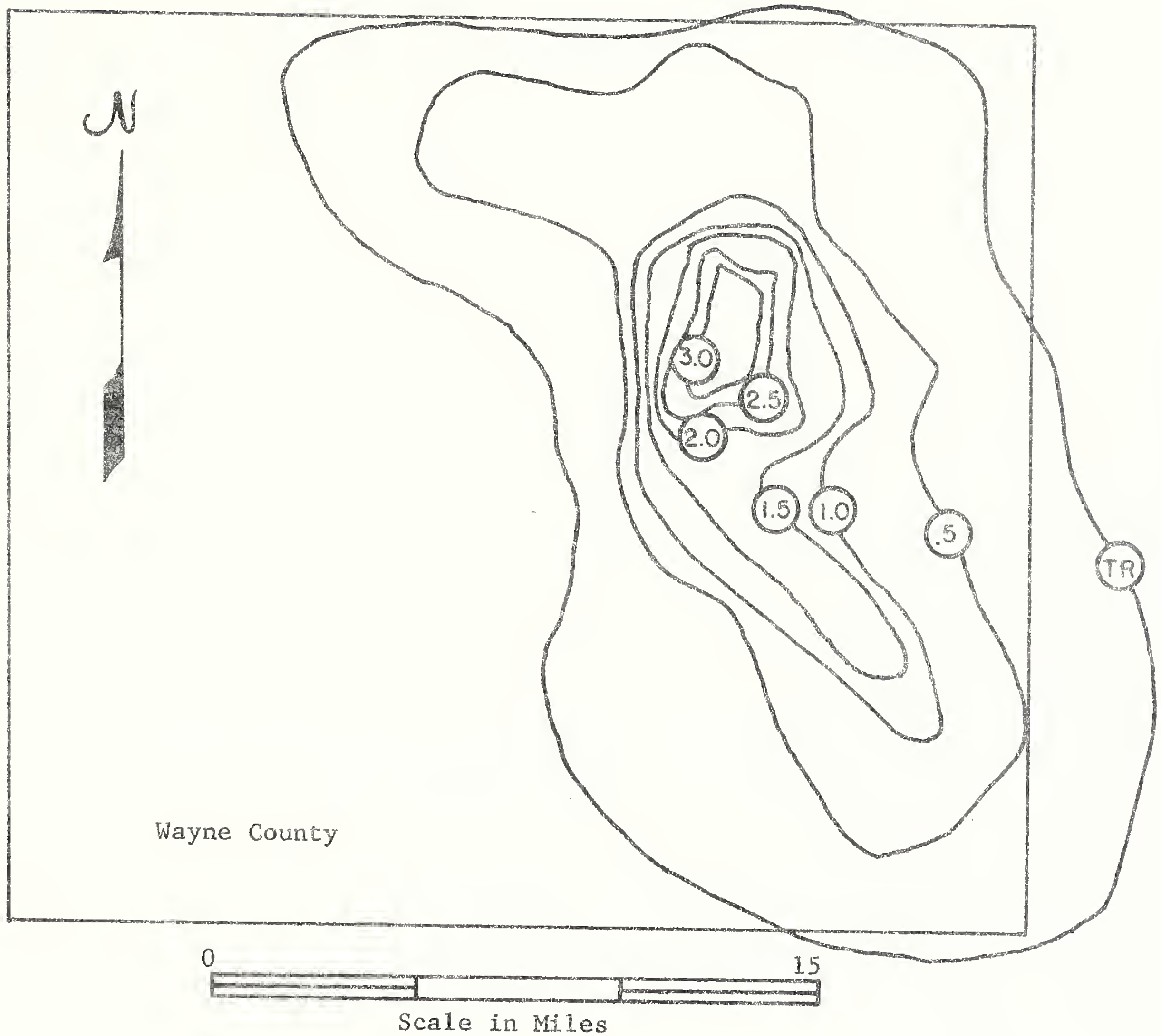


Fig. 11.1 -- Isohyetal map of June 12, 1970 storm.

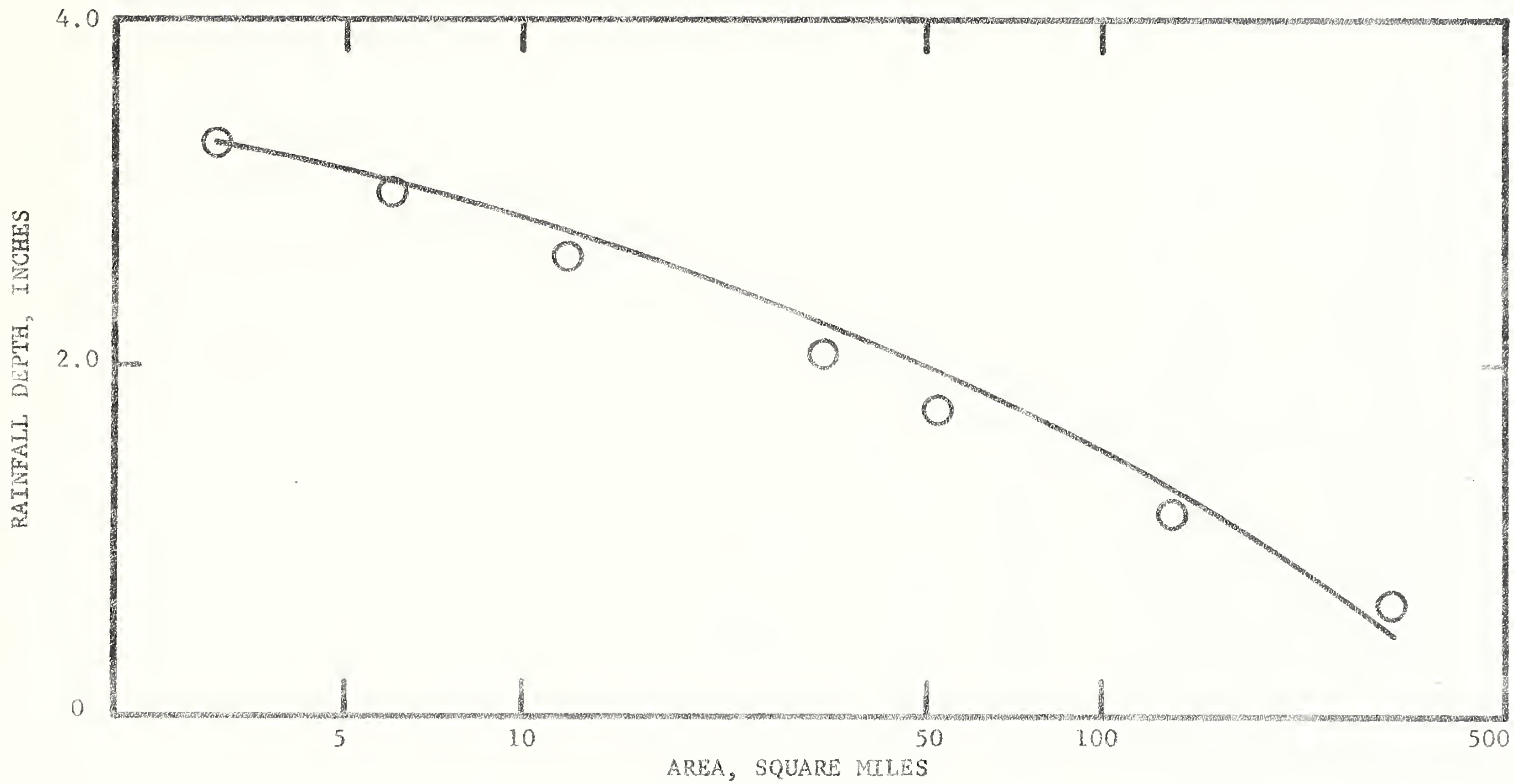


Fig. 11.2 -- Area-depth relations for storm of June 12, 1970. Solid line as measured from map. Circles from theoretical Gaussian distribution.

A. CRIS WORK UNIT: SWC-011 cCos-1

Research outline: Comparison of standard potential evapotranspiration (PET) from Coshocton lysimeter data with theoretical PET curves. Cos-68-13

B. LOCATION: Coshocton, Ohio

C. PERSONNEL: J. L. McGuinness, L. L. Harrold, F. W. Chichester, W. M. Edwards, and T. C. Wei; cooperators: Erich F. Bordne, Geography Department, Kent State University, and Ohio Agricultural and Research Development Center.

D. DATE OF PLANNED TERMINATION: 1970

E. OBJECTIVES: 1. To develop a standard curve of daily potential evapotranspiration (PET) for grass, derived from lysimeter data.

2. To compare the calculated standard PET curve with a variety of generally accepted theoretical curves on a daily and monthly basis.

F. NEED FOR STUDY: Little work has been done on the subject of agricultural use of water in humid areas. This lack of research on ET in humid areas has left a wide gap in our knowledge of the phenomena. Valid prediction of short-term ET amounts is a prerequisite to a complete understanding of the entire hydrologic system. Practically, the study should help in intelligent water planning, irrigation scheduling, etc., as well as being useful in improving the performance of mathematical watershed models.

G. DESIGN OF EXPERIMENT AND PROCEDURE TO BE FOLLOWED: Measured ET from the grassed lysimeter for the 1948 to 1965 period is converted to PET by (1) removing the influence of hay cut and (2) by correcting for the influence of limiting soil moisture. The data are then averaged for each of the 366 days of the year and a harmonic curve fitted to the data. Daily values taken from this fitted curve make up the standard PET curve of objective 1.

Average daily values of air temperature, humidity, radiation, wind and other climatic parameters are computed for the same 1948-1965 period used to derive the standard PET curve. These climatic averages are then used as input to compute PET by a variety of theoretical formulas. A total of 14 formulas are used, including Thornthwaite, Blaney-Criddle, Grassi,

Papadakis, Hamon, Turc, Makkink, Jensen-Haise, Stevens-Stewart, van Bavel, Penman, Christiansen, and Kohler-Nordenson-Fox.

H. EXPERIMENTAL DATA AND OBSERVATIONS: A synopsis of the data and findings of this project was given in the Annual Report for 1969. A short paper covering the subject was presented at the AGU meetings in April by Professor Bordne.

During the year the numerous calculations were checked, a complete revision of an earlier draft was made, and this revised draft was circulated to 18 people knowledgable in this field. After most of the reviewers' comments were received, another revised draft was made which has been submitted for Branch and Division approval as a Department publication (ARS-41 or Technical Bulletin).

I. COMMENTS, INTERPRETATIONS, AND FUTURE PLANS: A shorter journal article is now being drafted for submittal to Agricultural Meteorology. It is planned to terminate this outline early in 1971 upon completion of this journal article.

A. CRIS WORK UNIT: SWC-011 cCos-1

Research outline: Hydrologic systems of agricultural watersheds in the North Appalachian Region, Cos-68-14.

B. LOCATION: Coshocton, Ohio

C. PERSONNEL: L. L. Harrold, F. W. Chichester, W. M. Edwards, J. L. McGuinness, and T. C. Wei in cooperation with U. S. Hydrograph Laboratory (H. N. Holtan); N. E. Watershed Research Center, University Park, Pennsylvania (L. H. Parmele); Ohio State University, (Agric. Engin. Dept., E, Paul Taiganides and Civil Engin. Dept., V. Ricca).

D. DATE OF PLANNED TERMINATION: 1973

E. OBJECTIVES: To determine the relationships of watershed characteristics to water flux in different components of the watershed flow system as a basis of understanding water flux and transport of pollutants from agricultural watersheds.

F. NEED FOR STUDY: The only accurate and reliable device now known for obtaining watershed runoff from a rainfall event is the gaged watershed itself. The long-term records from gaged watersheds serve as a tool for developing concepts and solving many of the current problems in engineering hydrology. They also serve as a standard against which the various watershed models can be tested.

G. PROCEDURE: Numerical and conceptual results from components of the watershed flow system will be fitted together in mathematical watershed models.

H. EXPERIMENTAL DATA AND OBSERVATIONS:

I. COMMENTS, INTERPRETATIONS, AND FUTURE PLANS: This report consists of five sections as follows:

H-1 and I-1. USDAHL model studies
H-2 and I-2. Groundwater simulation, Stanford model
H-3 and I-3. Snowmelt, Stanford model
H-4 and I-4. Small watershed simulation, Stanford model
H-5 and I-5. Potential evapotranspiration frequency

H-1 USDAHL watershed model studies: Coshocton watershed data are being used by the U.S.D.A. Hydrograph Laboratory to develop and check segments of their watershed model based on measurable watershed and climatic parameters. Dr. T. C. Wei developed a working knowledge of this model in Beltsville and is adapting it to the Coshocton situation.

I-1 USDAHL watershed model studies will be given increased emphasis in 1971 under the direction of Dr. Wei. Data from Watershed 166 will be used to test the adaptability of the model. Further studies will utilize data from the Watershed 174-194-196 complex and possibly the Little Mill Creek areas.

H-2 Groundwater simulation, Stanford model: Work in this section was done by S. M. Owen as a masters thesis in the Civil Engineering Department, the Ohio State University. The thesis title is "Modification of the Stanford Watershed Model IV to improve groundwater simulation for Stratified Geologic Regions."

In previous work there has been an over-synthesis of runoff during the fall months. Mr. Owens examined geological and climatological conditions and developed a program to determine multiple recession constants for areas of stratified geology to replace the single constant used in the Stanford Model IV.

I-2 Groundwater simulation was improved by the use of multiple recession constants judging by correlations of observed and predicted daily flow amounts and comparisons of timing of flow. Little improvement was made in the winter season since the new snowmelt routine reported below was not available until the end of this study. Future research should include the simultaneous use of the multiple recession constant development with the new snowmelt routine.

H-3 Snowmelt, Stanford model: A revision of the snowmelt routine of the Stanford Model was undertaken by W. L. Mease, Jr. as a master's thesis project in the Civil Engineering Department of the Ohio State University. The thesis title is "A Snowmelt Subroutine for Streamflow Simulation in Ohio."

In the Ohio area there are few, if any, snow storage observations normally needed in the Stanford model. Snow water storage was computed from observed precipitation and temperature data. Snowmelt input was obtained by the heat balance equation of pure physics plus a few empirical coefficients determined from the data.

I-3 Snowmelt subroutine was found to be workable and greatly improved correlations between synthesized and observed streamflow, in both amounts and timing. Hourly temperatures (rather than average daily) and a knowledge of the state of moisture in the soil (liquid or frozen) would improve the results.

H-4 Small watershed simulation, Stanford model: L. E. Valentine of the Civil Engineering Department, the Ohio State University made modifications to the Stanford model to shorten the original 15-minute computational scheme to smaller routing intervals. His master's thesis is entitled "Modification of the Stanford Streamflow Simulation Model IV for Analysis of Small Watersheds."

I-4 Small watershed simulation was tested on three major storms on watersheds of 1520, 349, and 122 acres. Decreasing the 15-minute routing interral to 5 and 3 minutes resulted in:

1. The peak occurring earlier.
2. Synthesized storm flows increasing.
3. Baseflow and interflow recession curves lowering.
4. No noticable change in storm yield volumes.

Although the time increment changes varied the individual storm hydrographs, the yields and average daily flows were relatively unaffected.

Valentine recommended the use of a 5-minute routing interval. Future efforts should be to reduce the time interval of precipitation input possibly to match that of the chosen routing interval.

H-5 Potential evapotranspiration frequency: A study on this subject was completed by J. L. McGuinness and Leslie H. Parmele (Northeast Branch) in response to a request from Marvin E. Jensen, Chairman, Consumptive Use Committee, ASCE. Parmele presented the results at a half-day technical session at the Phoenix ASCE meetings in January 1971 and a manuscript has been submitted for publication in their Proceedings.

A 15-year period of lake evaporation was examined as an index of potential evapotranspiration. For each month from April through November, maximum 1-, 3-, 7-, 15-day and monthly lake evaporation values were tabulated. Only the single maximum value for each duration was listed for each month.

A graphical fitting procedure (Agri. Handbook No. 259) was used to fit the modified log-normal distribution to the

40 data sets. In all cases the data were closely fitted by straight lines indicating that the underlying distribution is log-normal.

I-5 Potential evapotranspiration frequency parameters, mean $\bar{E}_L$, and coefficient of variability, Cv_L, were tabulated for each of the 40 data sets. These two parameters completely describe the log-normal distribution.

Examination of the tabular data showed that the parameters could be closely described by the equations:

$$\bar{E}_L = 1.235M - 0.0850M^2 + 0.179D - 0.00820MD - 3.834 \qquad (1),$$

$$Cv_L = 1.292M - 0.322M^2 + 0.000732D + 0.0328M^3 - 0.00116M^4 - 1.659 \qquad (2).$$

In these equations, M represents the month (April = 4, May = 5, etc.), and D is the duration in days for which the estimate is made. The equations generalize the information contained in the original 40 sets of data since they make it possible to estimate the frequency of PET for any duration from one day to one month for any month from April to November.

A similar set of equations were developed for measured lysimeter data for a deep-rooted grass-legume crop. Results were very similar to those presented above.

The most important factor influencing the magnitude of PET is the magnitude of solar radiation. Inspection of a set of monthly maps of solar radiation (Bennett, Iven, "Monthly Maps of Mean Daily Insolation for the United States," Solar Energy 9 (3):145-158, 1965) shows that the areas near Coshocton are similar in amounts received to a broad belt extending from the Missouri-Illinois area in the west to the Pennsylvania-New York-New Jersey region in the east. Thus, the information condensed in equations (1) and (2) may be generally applicable over much of the east central United States.

A. CRIS WORK UNIT: SWC-011 cCos-1

Research outline: Runoff studies of small watersheds, Cos-68-15

B. LOCATION: Coshocton, Ohio

C. PERSONNEL: J. L. McGuinness, F. W. Chichester, W. M. Edwards, T. C. Wei, and L. L. Harrold in cooperation with Ohio Agricultural Research and Development Center, Wooster, Ohio.

D. DATE OF PLANNED TERMINATION: December 1971

E. OBJECTIVES: 1. To analyze the small single crop watershed data which have been collected under the previous research outline, Cos-61-4.

2. To determine and evaluate the factors affecting the volumes of surface runoff.

a. Soil type
b. Physical characteristics of soil
c. Antecedent soil water conditions
d. Vegetative cover
e. Management practices
f. Precipitation
g. Size and shape of the watershed
h. Geomorphic factors such as drainage density, slope, and watershed aspect.

3. Examine and evaluate the influence of the factors listed in objective 2 on such hydrograph characteristics as time of concentration, peak rate of runoff, and duration of runoff for each watershed.

4. To determine the best use of the small watersheds to meet the advancing programs in soil and water conservation and in the hydrologic systems approach to complex watershed analysis.

F. NEED FOR STUDY: Twenty-eight years of data are available from 1- and 2-acre single-crop watersheds in continuous pasture, meadow, and woods and from four paired crop-rotation watersheds managed in basic improved vs. prevailing practice. The long term program for these watersheds has been terminated and a final analysis of all the available data is to be made to wrap-up the program.

G. <u>PROCEDURE</u>: Many of the analyses of data from the small watersheds have been completed and a sampling of the results were given in the Annual Report for 1969. A comprehensive multiple regression analysis is underway to determine the relationships between volumes and peak rates and other variables such as precipitation amounts and intensities, antecedent soil moisture, cover, etc. Part of the available data will be used with the U. S. Hydrograph Laboratory Model.

H. <u>EXPERIMENTAL DATA AND OBSERVATIONS</u>: At a planning meeting early in 1970, it was decided to discontinue most of the basic small watershed program. The following watersheds were kept in operation in connection with ongoing pollution or tillage studies: 109, 106, 128, 113, 118, 123, 104, 191, 129, and 130. Watersheds 185 and 137 are on a part time status because of tillage studies. Discontinued watersheds include 103, 110, 111, 115, 121, 127, 131, 132, 135, 151, 188, and 192.

Flumes for discontinued watersheds were left in place. Land use for each area was determined largely by the programs which govern the complex watershed areas.

The soil sampling program on these watersheds as outlined in the Annual Report for 1969 was completed during 1970. Most of the testing program was also completed and part of the data have been analyzed. A complete report on this phase of the project should be completed during 1971 and a summary will be included in the next Annual Report.

I. <u>COMMENTS, INTERPRETATIONS, AND FUTURE PLANS</u>: During 1971 the main effort will be to complete the analyses of the small watershed data and to publish the results.

A. CRIS WORK UNIT: SWC-011 cCos-1

Research outline: Soil-water relations of agricultural watersheds, Cos-68-16

B. LOCATION: Coshocton, Ohio

C. PERSONNEL: W. M. Edwards, L. L. Harrold, J. L. McGuinness, F. W. Chichester, T. C. Wei in cooperation with Ohio Agricultural Research and Development Center, Wooster, Ohio.

D. DATE OF PLANNED TERMINATION: 1973

E. OBJECTIVES: 1. To develop and evaluate procedures for predicting the accretion, depletion, and storage of soil water at various depths on the agricultural watersheds under various land use and climatic influences.

2. To study movement of storm rainfall retention by soil depth and distance from ridge to watershed outlet and relate same to climatic and soil conditions.

3. To evaluate the zone of frozen soil and characterize type of frost structure as it affects infiltration, runoff, percolation, and soil water storage.

F. NEED FOR STUDY: Soil water storage and frost penetration are influenced by cover, soil type, tillage, and climate and in turn influence evapotranspiration, flood flows, subsurface hydrology, and water yield. Quantitative information on these influences and effects are needed for flow systems analysis in watershed engineering and water budgeting programs and in studies in the field of water management. The maintenance of a soil water inventory is needed as a major factor in evaluating the hydrologic performance of research watersheds.

G. PROCEDURE: Watersheds and monolith lysimeters are the experimental units upon which variables of crops and management practice are applied.

Soil water measurements are taken in watersheds and adjacent lysimeters as needed to develop normal depletion curves for different crops, soils, and soil layers and to relate runoff to rainfall and the initial soil water condition. Frost penetration data are obtained mostly by a sensing probe on an index plot of grass cover.

H. EXPERIMENTAL OBSERVATIONS AND DATA:

H-1 Evapotranspiration affected by mulch cover on no-tillage corn lysimeter.

Corn stover residue and manure mulch on no-tillage corn weighing lysimeter Y103A in second-year corn reduced evapotranspiration by 3.36 inches in the May-August period, 1970. Monthly values are given in table 16.1

Table 16.1.-Lysimeter Y103 ET.

Month	Conventional 1/	No-tillage	Difference
	In.	In.	In.
May	3.84	2.85	0.99
June	4.90	3.75	1.15
July	6.79	5.66	1.13
Aug.	5.21	5.12	.09
Total	20.74	17.38	3.36

1/ Computed from ET data from corn lysimeter Y102C in conventional tillage.

The relationship between daily ET on weighing lysimeters Y102C and Y103A was established by Harrold, Peters, Dreibelbis, McGuinness, "Transpiration Evaluation of Corn Grown on a Plastic-Covered Lysimeter."

$$ET_{Y103A} = 1.16\ ET_{Y102C} + 0.006$$

Daily ET values for Y103A (conventional) were computed from recorded values on Y102C. Corn on Y102C was planted by conventional spading, hoeing, and raking culture. The seedbed surface was clean and smooth. Computed values for Y103A represented ET under the same conventional-type tillage. However, the soil surface of Y103A was thoroughly covered with corn stover residue and barn manure. Corn was planted by hand through the mulch.

Soil water ET from the mulched no-tillage lysimeter Y103A, May, June, July was about 1 inch per month less than it would have been had the soil been exposed to solar energy as in conventional tillage. By August the corn plant canopy shielded the soil in both conventional and no-tillage culture. Evaporation from the soil under both surface conditions then became a minor factor in ET. Transpiration was the major

factor in August and was about equal for conventional (5.21 inches) and no-tillage (5.12 inches) corn culture.

H-2 Soil water under no-tillage and conventional corn on lysimeters.

Lysimeters Y103A and C were planted with the no-tillage techniques described above, while Y103B and D received the conventional corn tillage treatment as described above for Y102C. The four Y103 lysimeters are of Keene silt loam and were all in conventional corn in 1969.

Between June 10 and September 17, 1970, soil water measurements were made 10 times. In the 0-7 inch layer, determinations were made by fiberglass-gypsum blocks. For greater depths, the neutron probe was used.

Figure 16.1 shows soil water content for the 0- to 7-inch and 0- to 15-inch depths on days measurements were taken, along with daily rainfall. Lines connecting the data points have no meaning.

In the 0- to 7-inch layer, a treatment effect upon soil water was not indicated until the middle of July. From then until early September, there appeared to be more soil water under the mulch or no-tillage plot.

The same trend is shown for the 0- to 15-inch depth and was observed in data from depths reaching 5 feet.

I. COMMENTS, INTERPRETATIONS, AND FUTURE PLANS:

The strong difference in growing season soil water content under no-tillage and conventional corn practices shown in past years (see annual report 1965, 1966, 1967) was not evident in 1970. Approximately 3.5 inches of rain in each month, May, June, and July of 1970, replenished much of the water used in ET and kept strong soil water deficiencies from developing under either treatment.

The reduced ET from the mulch covered lysimeters is accompanied by greater subsoil moisture, which is consistent with earlier data. Deeper recharge under no-tillage than conventional corn in response to growing season rainfall has been shown and is consistent with the demonstrated ET reduction.

Continuation of the same treatments on lysimeter Y103 is planned. Until more years of ET and soil moisture data are available, more extensive interpretations regarding the effects of no-tillage on the Keene soil cannot be made.

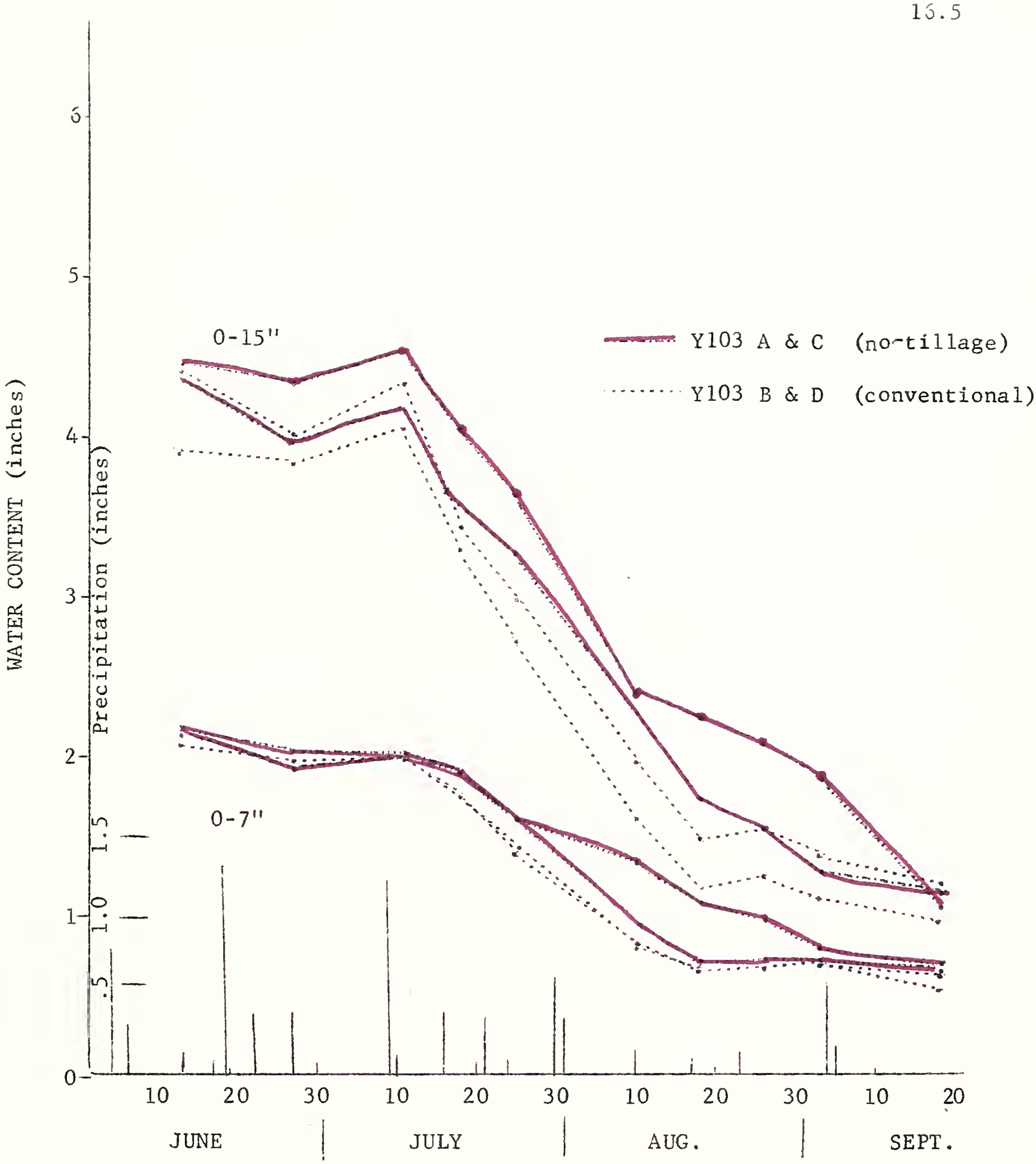


Figure 16.1.-Inches of water in the surface soils of two conventional corn lysimeters (Y103 B & D) and two no-till corn lysimeters (Y103 A & C) during Summer 1970 - Keene silt loam.

A. CRIS WORK UNIT: SWC-011 cCos-1

Research outline: Studies of precipitation characteristics influencing runoff from agricultural watersheds, Cos-68-17.

B. LOCATION: Coshocton, Ohio

C. PERSONNEL: J. L. McGuinness, F. W. Chichester, W. M. Edwards, L. L. Harrold, and T. C. Wei, in cooperation with Ohio Agricultural Research and Development Center, Wooster, Ohio.

D. DATE OF PLANNED TERMINATION: 1973

E. OBJECTIVES: 1. Determine the effect of exposure on rain gage catch.

2. Determine the influence of rainfall characteristics on surface runoff from very small watersheds.

3. Determine whether a seasonal trend exists in the relationship between Fischer & Porter and other gages.

F. NEED FOR STUDY: Precipitation measurements are the basic input for most hydrologic analysis. Readings are made at a point on or near a watershed and these readings are then extrapolated to represent the precipitation falling on many acres or even square miles of countryside. There are, however, two fundamental difficulties with this scheme: (a) the measurement at the gage site may not represent the true ground precipitation at that point, and (b) the point measurement may be representative of only a comparatively small area in the vicinity of the gage.

The crux of the difficulty lies in our inability to measure "true" ground precipitation at a point. This is basically a reflection of the lack of an absolute standard against which gage performance may be judged. Obtaining a "true" point measurement should be the most important objective of this outline but procedures for solving this problem are not now known.

G. PROCEDURES: First priority is being given to putting the large backlog of precipitation data on magnetic tape. Most of the analyses tentatively planned under this outline such as the relation of topographic effects on catch are contingent upon ready availability of that data.

H. EXPERIMENTAL DATA AND OBSERVATIONS: Little progress was made in cutting down on the backlog of unpunched precipitation data. The main data processing program is virtually complete and the "blunder" check program has been upgraded with additional checks.

Objective 3 was reported as completed in last year's report with publication of a paper by McGuinness and Vaughan (ESSA) in Water Resources Research. In the October issue of that journal, Leslie H. Parmele published a comment stating that he did not find any seasonal trend in his data from Pennsylvania and West Virginia. The authors replied that they had not labeled all digital-standard data as biased -- only the specific sets they worked with -- and that most practicing hydrologists would use those data as published.

I. COMMENTS, INTERPRETATIONS, AND FUTURE PLANS: A more determined effort is scheduled this coming summer to cut down on the backlog of card punching. No further analyses are planned until after this task is finished.

A further comment on the Water Resources Research paper is now being processed. Boris Sevruk of the Federal Institute of Technology at Zurich has found a seasonal trend in comparing several gage types in Switzerland.

A. CRIS WORK UNIT: SWC-027 cCos-2

Research outline: Pollution of surface and subsurface water with chlorinated insecticides and other agricultural chemicals, Cos-68-12

B. LOCATION: Coshocton, Ohio

C. PERSONNEL: W. M. Edwards, L. L. Harrold, F. W. Chichester, T. C. Wei, J. L. McGuinness, Coshocton, Ohio; A. W. Taylor, J. H. Caro, H. P. Freeman, and E. C. Simpson, Beltsville, Maryland, in cooperation with the Ohio Agricultural Research and Development Center, Wooster, Ohio.

D. DATE OF PLANNED TERMINATION: 1973

E. OBJECTIVES: 1. To determine the degree to which nitrogen and phosphorus fertilizers and selected chlorinated insecticides are transported from agricultural lands.

2. To study the transport mechanisms involved in Objective No. 1 in order to control the movement of pollutants with land management or other practices.

3. To determine the movement of N, P, K, Methoxychlor, and 2, 4, 5-T from the land surface to depths below the root zone, by percolating water.

F. NEED FOR STUDY: Public concern over the quality of the water in streams, rivers, and lakes has led to a more critical evaluation of agricultural practices as they may effect the quality of the water that drains from the fields. As fish and other aquatic animals are very susceptible to small concentrations of persistent pesticides in water, reliable information is needed on the movement of pesticides from treated agricultural lands into the drainage system. This includes the magnitude and the mechanism of the movement and factors that influence the rate.

The role of agriculture in contributing to the development of algal scums and blooms in the lakes and rivers needs to be evaluated. These blooms have been attributed primarily to accumulation of nitrates and phosphates in the waterways. Research is needed to evaluate the magnitude and mechanisms by which these elements are transported from farmlands to the waterways.

G. PROCEDURE: 1. Watersheds having a substantial log of climatic and hydrologic data, to supply answers to questions regarding the relation of agriculture to water quality,are treated with insecticide and plant nutrients. The movement of dieldrin, nitrates, and phosphates downward through the soil profile and laterally across the sloping surface of the hill, as well as losses resulting from erosion and runoff are studied.

Periodic sampling of the soil is scheduled to provide measures of balance of pollutants. Samples of surface runoff water and eroded solids from each watershed are collected during each storm. Solids are separated from the liquid and both fractions retained for analysis. Plant samples from the experimental areas are taken at the end of the growing season to determine the chemicals removed by harvest. All samples are sent to the U. S. Soils Laboratory, Beltsville, Maryland for chemical analysis. Samples are analyzed for the chlorinated pesticides under investigation as well as their degradation products. They are also analyzed for their nitrate, chloride, potassium, ammonium, and phosphate contents, when applicable.

2. Lysimeters are treated with pesticides and plant nutrients. One lysimeter is used as a check and receives no treatment.

The concentration of chemicals in the samples, combined with the volumes of runoff and percolation indicates the extent to which these potential pollutants persist in the soil water system and contaminate surface runoff and ground water.

H. EXPERIMENTAL DATA AND OBSERVATIONS:

H-1 The Fate of Dieldrin Following Field Application:

During 1970 there was no new dieldrin treatment on any small watersheds. Sample collection from watersheds treated in 1966, 1968, and 1969 were continued.

With 4 years (one full rotation) completed, runoff data have been summarized and some conclusions reported. The following is a statement of results as presented in the proceedings of the Symposium on the Interdisciplinary Aspects of Watershed Management, ASCE-ASAE, August 1970, by J. H. Caro, W. M. Edwards, B. L. Glass, and M. H. Frere.

> "The pesticide lost in the runoff water from the separate watersheds was only a small proportion of the total applied, ranging from a low of 0.007% in three years to a high of 0.07% in one year. Relatively high pesticide loss resulted only when runoff occurred within three months of application, before establishment of a full cover crop on the treated area. Concentrations in the runoff water during this period ranged up to 20 micrograms of dieldrin per liter (ppb). Concentrations after three months were always below 5 micrograms per liter, falling to less then 2 micrograms per liter in the second year. The concentrations in individual runoff occurrences bore no relationship to volume, intensity, or duration of runoff.

"When erosion occurred, relatively large amounts of dieldrin were lost by this pathway. On one watershed, 2.2% of the applied dieldrin was removed in the sediment during the first season after application, about 30-fold that in the associated runoff water.

" It is important to recognize that the experiments were conducted on steeply sloping plots and that the largest observed losses of pesticide occurred under conditions in which an attempt was made to increase runoff and erosion of topsoil. Hence, these losses should be regarded as maxima. With the institution of recommended conservation practices, losses of pesticide in both runoff water and sediment could be considerably reduced or even effectively eliminated."

Similar summaries describing dieldrin losses through crop uptake, volatilization, and degradation in the soil have been made and are in the process of being published.

H-2 Methoxychlor and 2, 4, 5-T in Lysimeter Percolation and Runoff Water:

Results of a study defining the fate of a surface application of 2, 4, 5-T and methoxychlor on lysimeter Y101B have been summarized and prepared for publication. The following is taken from an article by Edwards and Glass, "Methoxyghlor and 2, 4, 5-T in lysimeter percolation and runoff water." It will appear in Bulletin of Environmental Contamination and Toxicology in 1971.

Lysimeter runoff and percolation resulting from natural rainfall were monitored for 14 months following the March 30, 1967 surface application of 11.2 and 22.4 kg per ha of 2,4,5-T and methoxychlor, respectively.

Runoff in this period carried over 5.5 g/ha or 0.05 percent of the applied 2,4,5-T. As evident in Table 12.1, the bulk of the 2,4,5-T removal in the runoff took place within the first 4 months after application, and more than half of the loss took place within 32 days. Over 25 percent of the entire loss was associated with one storm event occurring 21 days after application, when the concentration in the runoff reached a maximum of 380 $\mu g/1$. It is noteworthy that the amount of runoff water during this event was relatively small (4.4 1).

In contrast, the methoxychlor concentration was generally low for the first 3 months after application, April - June, when 18 percent of the period's runoff carried only 8 percent of the insecticide removed. Somewhat higher concentrations prevailed through January 1968, when a single event, which occurred when the surface soil was frozen, removed more methoxychlor than all other events combined. Although the methoxychlor concentration in the

Table 12.1.-Methoxychlor and 2,4,5-T in lysimeter runoff in the 14-month period following March 30, 1967 application

Sample date	Days after application	Concentration (μg/liter) 2,4,5-T	Concentration (μg/liter) Methoxychlor	Runoff (liter)
1967				
4-5	6	105	0.1	2.2
4-17	18	197	8.8	6.6
4-21	22	380	1.3	4.4
5-2	33	170	1.0	2.2
5-7	38	52	1.0	4.4
5-15	46	59	.8	8.8
5-29	60	82	.2	6.6
7-2	94	68	2.2	4.4
7-19	121	30	7.8	8.8
7-24	126	(25)	4.7	4.4
8-20	143	13	(5.5)	11.1
9-9	163	10	(5.5)	2.2
9-28	182	2	6.3	13.6
11-1	216	3	.6	8.8
1968				
1-27	303	(3)	5.3	86.2
3-22	357	2	1.1	11.1
3-27	362	1	2.0	4.4
3-31	366	1	2.0	2.2
4-14	380	3	3.4	6.6
5-24	420	1	1.3	22.1
				221.1

Data in parentheses are estimates

runoff was no higher than that of several earlier events, the removal was high because of the relatively large volume of runoff, 86.2 l. Only because the topsoil was frozen, was the event significant. The rain which produced this runoff fell at low intensities and would have infiltrated, had the soil not been frozen.

Total methoxychlor removed by runoff during the 14-month period was 0.8 g/ha -- 0.004 percent c the application.

Runoff for the study period totaled 274 mm, about the same as the 20-year average.

Percolate, water intercepted below the rooting depth at 2.44 m, contained no methoxychlor and only trace amounts of 2,4,5-T. The first indication that the chemical had moved down through the soil material to the lysimeter bottom was a concentration of 0.5 ppb of 2,4,5-T on December 6, 1967, 9 months after application. Samples taken on March 25 and 28, 1968, 1 year after application, contained 0.1 ppb, although none was detected in most of the samples taken during this period.

Percolation for the study period totaled 265 mm, about 100 mm less than the 20-year average.

Publication of this article terminates research under objective 3 of this outline.

H-3 <u>Nutrients in Stream Runoff:</u>

Progress in sampling and analyzing stream samples for nutrient quality studies has been reported in each annual report since 1966. In 1970 monitoring was continued and a publication was prepared by A. W. Taylor, W. M. Edwards and E. C. Simpson which summarizes 4 years of stream water quality data. The following is the abstract of the paper "Nutrients in streams draining woodland and farmland near Coshocton, Ohio," appearing in the February 1971 issue of Water Resources Research.

"ABSTRACT. Nitrogen, phosphate and potassium concentrations were measured in streams draining woodland and farmland watersheds at Coshocton, Ohio in 1966 through 1969. Temporal variations in the nutrient concentrations were much smaller than the changes in the rate of streamflow. No relationship was found between any nutrient concentration and streamflow, and no seasonal changes in concentration were detected. Nutrient losses were significantly greater from farmland than from woodland. The nitrate-N concentration in the farm runoff was below 2 ppm except for one short period when it rose to 10 ppm. The input of nitrogen in the rain was greater than the loss in

runoff from both watersheds. The average concentration of phosphate in runoff was 22 ppb (of P) from the farm and 15 ppb from the woodland. The analysis of the data shows that total nutrient losses cannot be calculated meaningfully unless both hydrologic and chemical data are available. The volume of waterflow is the most important variable in this calculation."

The above report defines nutrient transport in permanent streams on the Research Station. Similar data for runoff from 1 to 8 acre single-crop watersheds are being evaluated in order to relate runoff water quality to management practices.

I. COMMENTS, INTERPRETATIONS AND FUTURE PLANS: Sampling will continue on dieldrin treated watersheds to define long-time effects following earlier treatments. Future insecticide treatments will be with a carbamate rather than a chlorinated hydrocarbon. Uptake of dieldrin by soybeans grown in soil treated 1, 2, 3, or 4 years earlier will be evaluated with the analysis of samples collected in 1970 from watersheds 128, 111, 106, and 109.

Future nutrient studies will be done under the direction of Dr. F. W. Chichester, utilizing the newly renovated chemistry laboratory and facilities. This will enable nitrogen and phosphorus determinations to be done at Coshocton with much less delay between sampling and analysis.

Using techniques similar to those used with methoxychlor and 2, 4, 5-T, the fate of a surface application of Picloram on lysimeter Y101C will be evaluated. Treatment was made on March 25, 1970. Runoff and percolation samples are currently being analyzed.

A. CRIS WORK UNIT: SWC-027 cCos-2

Research outline: The effect of a small barnyard on downstream water quality, Cos-68-18

B. LOCATION: Coshocton, Ohio

C. PERSONNEL: W. M. Edwards, F. W. Chichester, L. L. Harrold, T. C. Wei, J. L. McGuinness, Coshocton, Ohio; A. W. Taylor, J. H. Caro, H. P. Freeman, and E. C. Simpson, Beltsville, Maryland; and R. K. White, Ohio Agricultural Research and Development Center, Wooster, Ohio.

D. DATE OF PLANNED TERMINATION: 1973

E. OBJECTIVES: 1. To evaluate water pollution in surface streamflow immediately below a small beef cattle feedlot with respect to individual runoff producing storms and annual surface water yield.

2. To determine the extent to which the form and concentration of pollutants are affected as they flow downstream and are diluted by surface and subsurface flow from other areas.

F. NEED FOR STUDY: Recent concern over the quality of the water in streams, rivers, and lakes has led to a more critical evaluation of agricultural practices as they may affect the quality of the water that drains from agricultural lands. Areas having high livestock concentrations normally have high concentrations of potential pollutants such as nitrogen and phosphorus. Additional research is needed to evaluate the magnitude and mechanisms by which these elements are transported from barnyards to the waterways.

G. PROCEDURE: Mixed cover watershed 177 (30 ha) and a barnyard feedlot watershed no. 163 (0.17 ha) are the experimental units upon which the following treatments are applied.

1. Barnyard (163):

   a. From 30 to 65 beef cattle are confined in the barnyard at different times during the fall, winter, and spring months.
   b. A grass-filled trench silo in the barnyard is opened during the winter months.

2. Mixed cover watershed (177):

   a. Corn, wheat, meadow, meadow rotation on cropped fields.
   b. Fertilizer applications consistent with good farm management practices.
   c. 13 to 18 tons (metric)/ha of manure spread in the winter on winter wheat and on sod land that will be plowed down for corn the following summer.

Runoff from a 0.17 ha beef cattle barnyard is sampled automatically and the concentration, form, and total amount of pollutants leaving the barnyard in the runoff, is determined.

Downstream samples are collected at flume 177, the outlet of a 500 meter long grass waterway. Analysis of samples from this downstream site gives information on the effect of chemical changes in the form of pollutants as well as the dilution by addition of water to streamflow from sources other than the feedlot.

Values of chemical concentration in the liquid and solid phases of runoff are applied to flow rates for each sample to get transport rates of the chemicals studied. This rate curve is integrated mathematically to get values of total chemicals removed per storm, month, season, and year.

H. <u>EXPERIMENTAL OBSERVATIONS AND DATA</u>: In the period between 3-31-68 and 12-31-69, 199 runoff samples were collected at the barnlot watershed (ws 163) and analysed for NO_3-N, NH_4-N, N(org), N(tot), P(tot), K, and Cl. A summary of these data showing monthly minima, maxima, and mean concentrations is presented in table 18.1. Monthly mean concentrations of NO_3-N, N(tot), P, K, and Cl are plotted in figure 18.1.

Concentration of these same five nutrient forms at flume 177, 500 meters downstream, is shown in figure 18.2 for the 1966 through 1970 period.

From May through December, 1970, all barnlot runoff was intercepted, temporarily stored in a rubber lined pit, and subsequently sprinkled on adjacent pasture land at a rate that precluded runoff. Water quality before and during "pit operation" is also shown in figure 18.2.

Nutrient transport values were obtained by multiplying nutrient concentrations by measured runoff volumes. The ratio of nutrient concentration (ws 163/ws 177) and the ratio of nutrient transport (ws 177/ws 163) are shown in figure 18.3.

Table 18.1.-Minimum, maximum, and mean[1/] concentration of nutrients (ppm) in barnlot runoff, watershed 163, Coshocton, Ohio, 1968-1969.

Month	NO_3-N	NH_4-N	N(org)	N(tot)	P(tot)	K	Cl
Jan.	0.2 - 4.0 1.6	16.4 - 51.0 37.0	40.6 - 90.2 65.0	41.4 - 94.2 67.8	3.4 - 10.2 5.8	260 - 330 295	77.1 - 99.9 89.0
Feb.[2/]	1.1	35.0	66.0	63.0	6.0	345	114
Mar.	.2 - 5.6 1.2	5.8 - 48.0 22.0	22.2 - 101 66.8	27.8 - 101 57.9	2.8 - 7.6 5.8	122 - 610 421	55.9 - 401 232
Apr.	.4 - 1.6 1.2	5.6 - 23.2 10.8	22.8 - 75.9 48.7	23.8 - 77.5 50.7	2.4 - 10.2 5.4	120 - 655 321	46.4 - 384 170
May	.2 - 1.6 0.5	2.8 - 9.6 5.3	11.3 - 52.4 28.1	11.7 - 52.6 31.4	.7 - 11.6 4.7	135 - 640 276	58.9 - 374 150
June	.2 - 4.9 1.3	.4 - 8.5 2.6	2.5 - 22.4 10.1	3.5 - 24.3 12.2	1.5 - 6.4 3.3	53.0 - 325 160	6.0 - 152 65.3
July	1.3 - 35.6 4.8	.6 - 7.2 1.8	2.1 - 13.9 6.1	3.4 - 45.7 12.5	1.0 - 3.5 2.4	39.0 - 262 117	6.0 - 86.6 34.7
Aug.	4.8 - 7.8 5.8	.4 - 1.6 .9	3.4 - 8.8 6.0	12.6 - 33.7 17.1	1.0 - 2.0 1.4	74.0 - 180 122	17.3 - 43.2 30.0
Sept.	8.6 - 13.6 9.6	1.2 - 2.8 1.6	3.9 - 5.2 4.9	12.5 - 18.8 13.8	1.4 - 1.9 1.5	65.0 - 114 81.2	26.0 - 42.0 29.7
Oct.	.1 - 32.2 7.1	1.4 - 13.2 7.4	8.1 - 39.9 23.2	12.0 - 60.8 34.1	5.1 - 21.4 13.3	140 - 197 174	36.1 - 130 76.8
Nov.	.1 - 8.0 2.6	4.8 - 21.2 12.7	10.8 - 45.9 30.7	18.8 - 46.3 34.8	5.1 - 10.2 7.3	130 - 295 211	38.0 - 124 83.3
Dec.	.1 - 1.6 .9	12.5 - 36.0 20.8	25.2 - 68.4 36.6	25.3 - 69.8 45.0	5.0 - 7.9 5.5	79.0 - 305 159	35.5 - 103 64.0

1/ .2 - 4.0 / 1.6 = minimum - maximum / mean

2/ No samples collected during February 1968 or 1969.

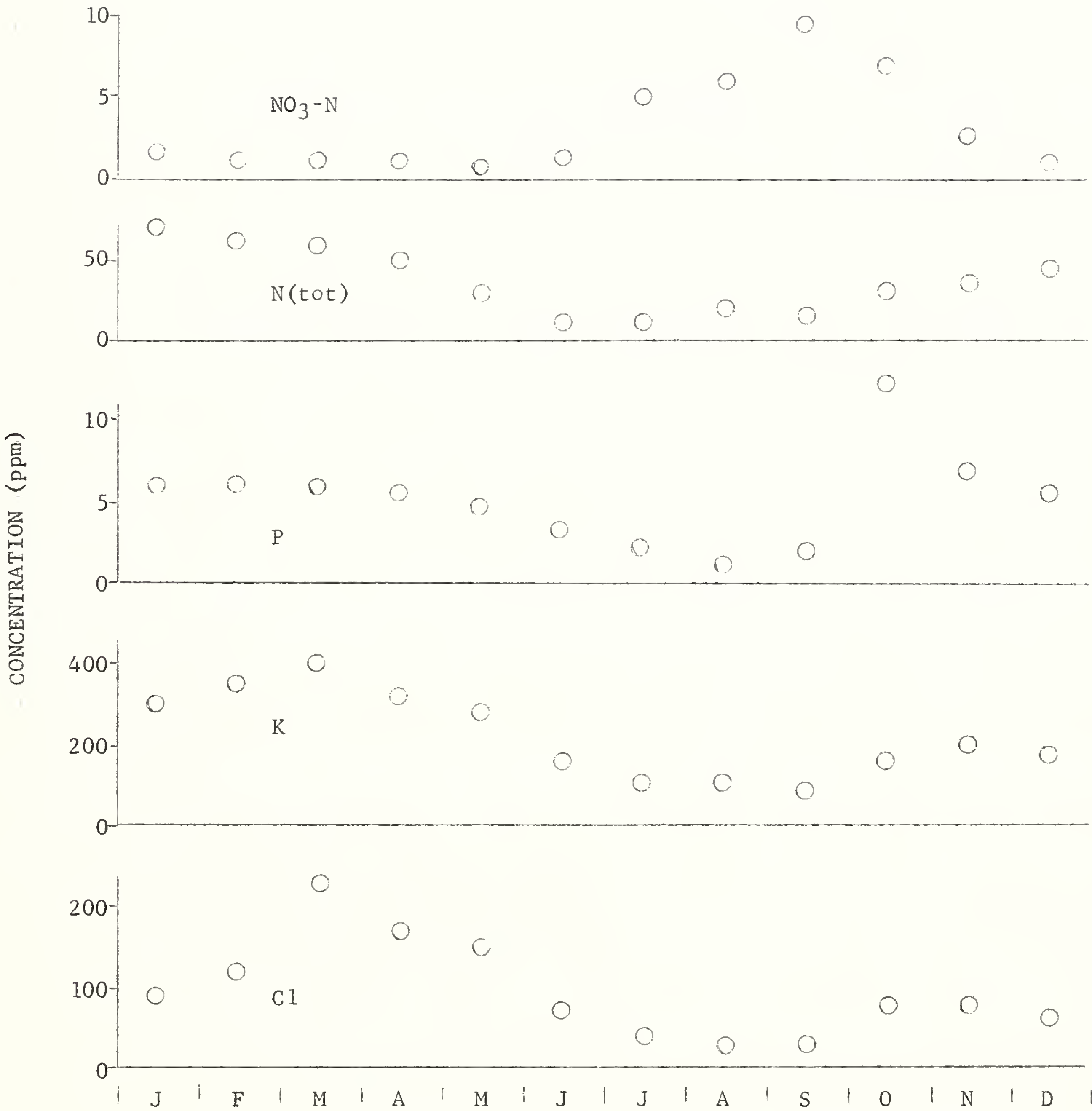


Figure 18.1.-Mean monthly nutrient concentrations in barnyard runoff, ws 163, March 1968 thru December 1969.

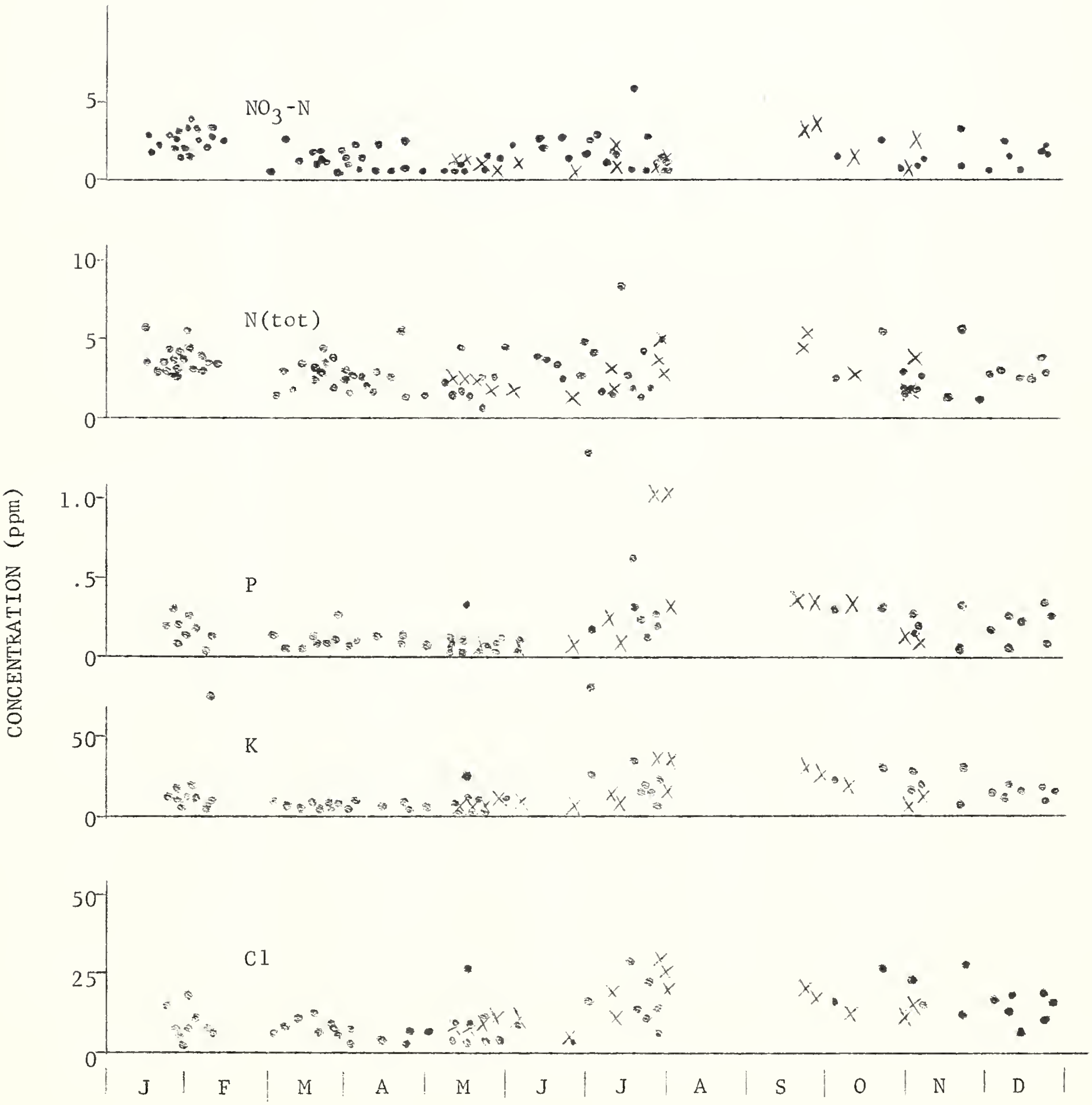


Figure 18.2.-Nutrient concentrations at F177, 500 m below barnlot watershed no. 163 for the period January 1966 thru April 1970 (dots) and May 1970 thru December 1970 (x's).

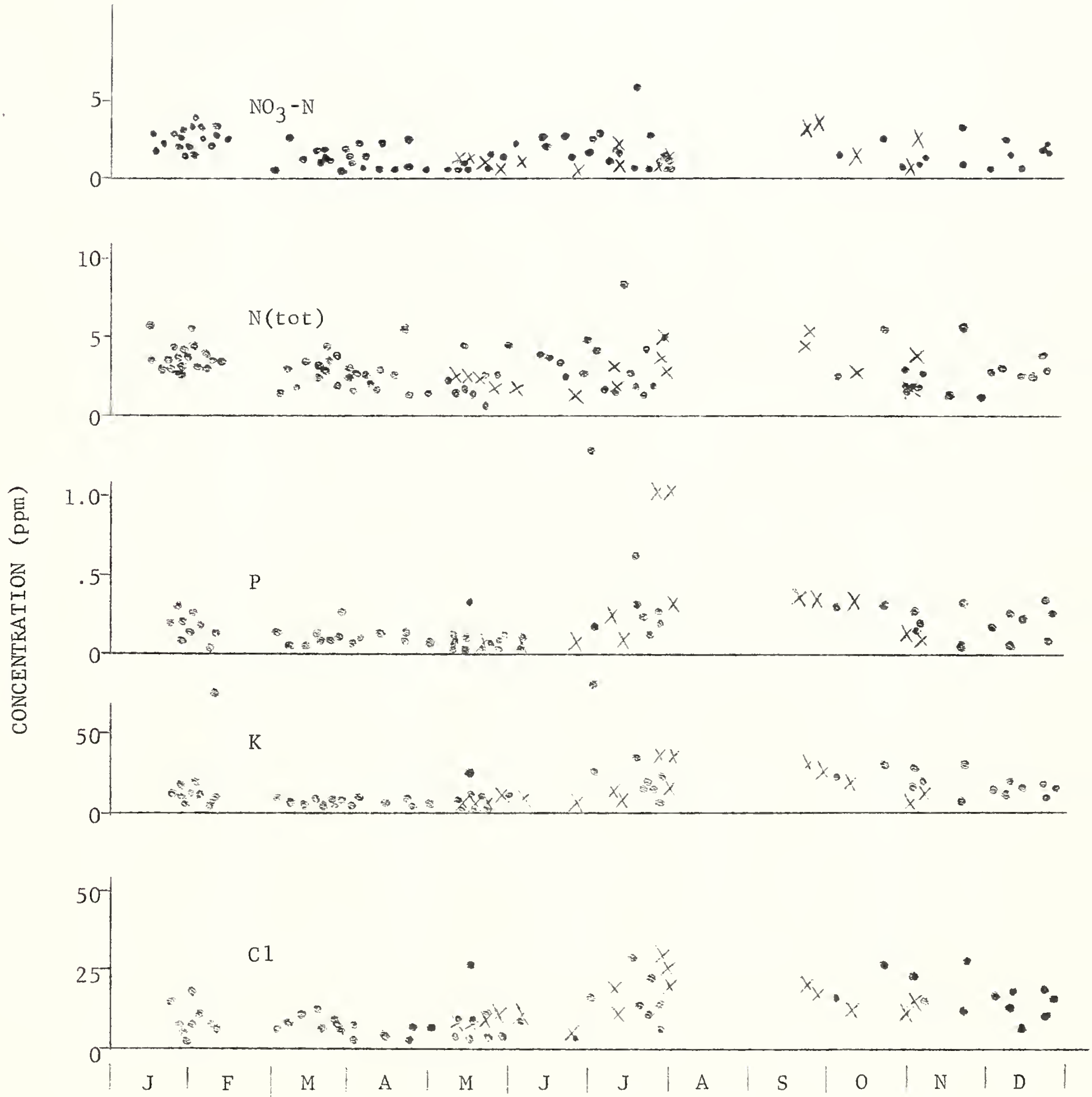


Figure 18.2.-Nutrient concentrations at F177, 500 m below barnlot watershed no. 163 for the period January 1966 thru April 1970 (dots) and May 1970 thru December 1970 (x's).

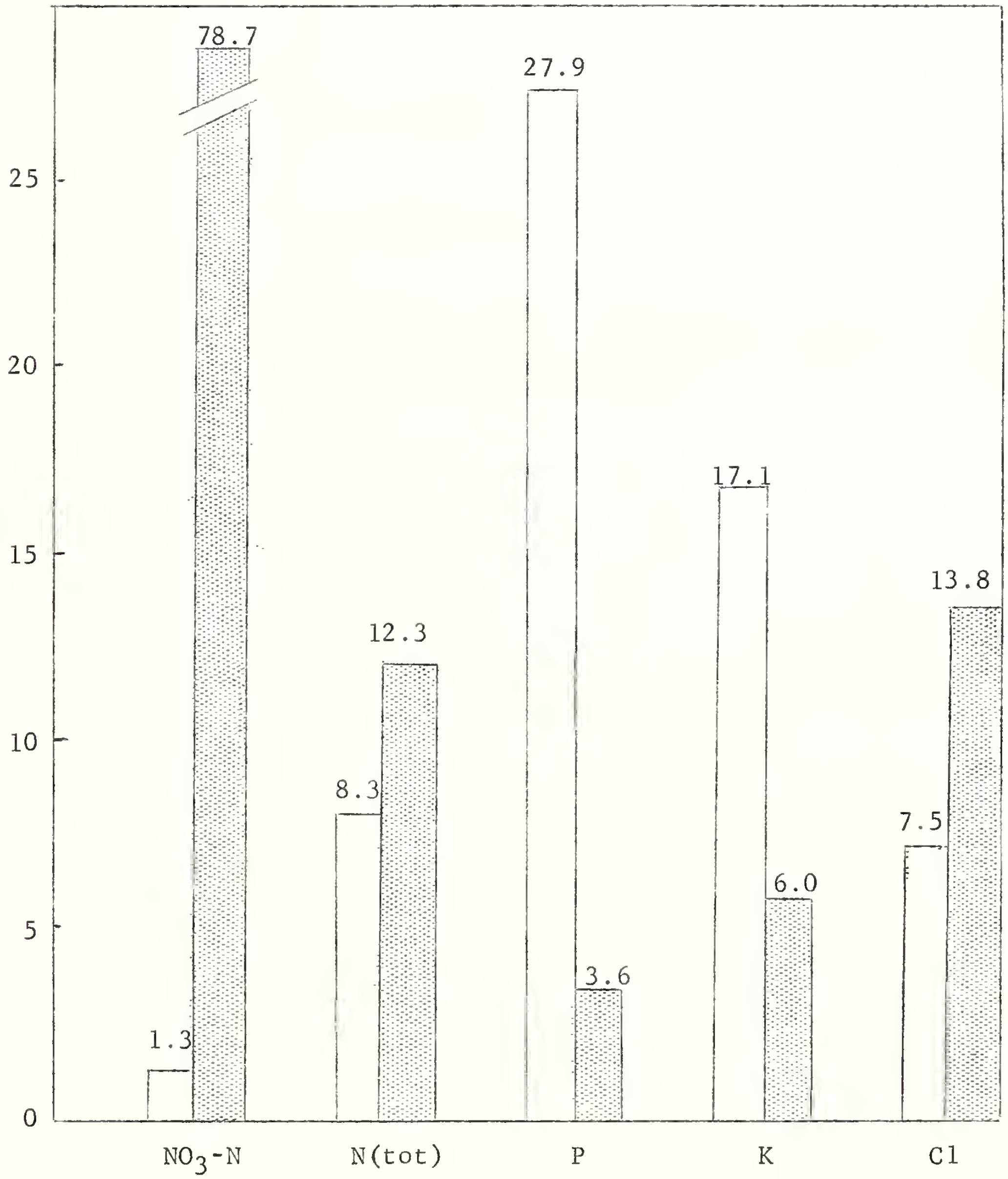


Figure 18.3.-Ratio of nutrient concentrations (ws 163/ws 177, open bars) and nutrient transports (ws 177/ws 163, solid bars).

I. <u>COMMENTS INTERPRETATIONS, AND FUTURE PLANS</u>: Data in table 18.1 and figure 18.1 describe quality of runoff water coming from a typical eastern Ohio beef cattle barnlot. This is an assessment of the contribution to enrivonmental pollution from one of agriculture's potential "hot spots."

The barnlot watershed was described in the 1969 annual report as was the 1969 runoff and sampling pattern. A complete summary of all data through 1970 is being assembled into a publication by W. M. Edwards, E. C. Simpson and M. J. Frere. The following abstract summarizes the results and interpretations of the barnlot runoff water quality study to this date.

"Runoff from a 60-head beef cattle barnlot was measured, and concentrations of nitrate, ammonium, organic and total nitrogen, total phosphorus, potassium, and chloride in solution were determined. Nitrate nitrogen concentration was <2 ppm for 7 months of the year, and the peak monthly concentration was <10 ppm. Most of the soluble N is in a reduced form with the maximum monthly concentration <70 ppm. Average phosphorus concentration is 6 ppm during winter and spring, lower in the summer, with a peak near 10 ppm in October.

"Nitrate concentration increased during warm months when environmental conditions favored oxidation. Concentration of all other nutrient forms decreased during the summer. The concentration of reduced forms of nitrogen had a high negative correlation with temperature."

Runoff leaving the barnlot entered a 500 meter long grass waterway where it mixed with runoff from 30 hectares of cropland and pasture. Samples collected at the waterway outlet showed that nutrient concentrations were strongly reduced below those at the barnlot (fig. 18.2). Nitrate nitrogen concentration was reduced by a factor of only 1.3, showing that the runoff from the surrounding areas contributed much of this form of nitrogen. There was nearly a 28-fold decrease in phosphorus concentration, however, indicating that the 0.17 ha barnlot was a major source of phosphorus within the 30 ha mixed farming watershed.

Transport of nitrate from the 30 ha mixed watershed, of which the 0.17 ha barnlot was a part, was 78.7 times more than that from the barnlot alone. Because the P concentration in flow at the barnlot was 27.9 times that at the waterway outlet, phosphorus transport at the waterway outlet was only 3.6 times that from the barnlot.

The x's of figure 18.2 represent concentrations in samples taken at the waterway outlet after May 1, 1970, when barnlot runoff was being diverted into the storage pit. Dots are data points reflecting nutrient content prior to the pit operation. As shown in figure 18.2, runoff water quality did not improve at the waterway outlet during the last 8 months of 1970, when the barnlot was not contributing runoff to the waterway system.

A. CRIS WORK UNIT: SWC-012 cCos-3

Research outline: Studies in subsurface hydrology, Cos-69-19.

B. LOCATION: Coshocton, Ohio

C. PERSONNEL: J. L. McGuinness, L. L. Harrold, W. M. Edwards, F. W. Chichester, and T. C. Wei, in cooperation with the Ohio Agricultural Research and Development Center, Wooster, Ohio.

D. DATE OF PLANNED TERMINATION: 1970

E. OBJECTIVES: 1. To develop and evaluate procedures for predicting the accretion, storage, and depletion of groundwater from a multi-aquifer system in agricultural watersheds.

2. To define physical properties of geologic materials which transmit or retard subsurface water movement.

3. To develop techniques of measuring the water conductance capacities of fractured sedimentary rock using hydraulic, geophysical and mechanical techniques.

4. To determine the effect of geology upon the discharge from perched water tables as it interacts with surface, shallow subsurface waterflow and return flow.

F. NEED FOR STUDY: Lack of knowledge of the movement of subsurface water and its interaction with soil water and surface runoff remains as a major deterrent to synthesizing the water cycle in a hydrologic model.

G. PROCEDURE: Water level data on Well 153 have been tabulated for a primary recession period. Analyses have been made to assess the effects of barometric pressure on well levels. Standard computational techniques for transmissibility, storativity, permeability, and other aquifer constants may be applied.

Basic hydrogeologic data from wells and springs have been tabulated and are available in punch-card form. An attempt will be made to describe the accretion-depletion relationships of the wells in terms of other variables such as precipitation, soil moisture, evapotranspiration, etc.

H. EXPERIMENTAL DATA AND OBSERVATIONS: The analysis of fluctuations of water levels in Well 153 is based on the material in

Ground Water Hydrology by David K. Todd, John Wiley and Sons, Inc., New York, 336 pp., 1959 (pp. 158-163).

Well 153 is located near a hardwoods-pasture boundary about 600 feet north of gage 174. The well is on a side hill near the aquifer outcrop and is bottomed in the clay underlying the Putnam Hill limestone. The well log is given in fig. 19.1 along with the symbols used in this analysis. The aquifer is 8.3 feet thick extending from the top of sandstone to top of clay. The aquiclude is primarily the 4.2 feet of shale overlying the sandstone.

Using Todd's symbols and numbering system, if Δp_a is the change in atmospheric pressure and Δp_w is the resulting change in hydrostatic pressure at the top of a confined aquifer, then

$$\Delta p_a = \Delta p_w + \Delta s_c \qquad (6.3)$$

where Δs_c is the increased compressive stress on the aquifer. Thus, an increase in atmospheric pressure, Δp_a, is balanced by an increase in the pressure on the water, Δp_w, and by an increase in pressure on the elastic body of the aquifer itself, Δs_c.

For a static condition at a well penetrating the confined aquifer, the relation

$$p_w = p_a + \gamma h \qquad (6.4)$$

exists where γ is the specific weight of water. Then if the atmospheric pressure increases by Δp_a, we have

$$p_w + \Delta p_w = p_a + \Delta p_a + \gamma h' \qquad (6.5)$$

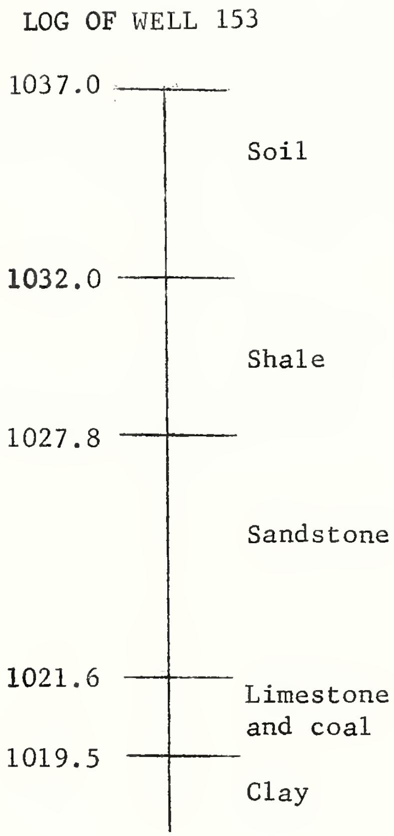
where h' is the new water level needed to balance the forces. Substituting for p_w from equation (6.4) gives

$$\Delta p_w = \Delta p_a + \gamma(h' - h). \qquad (6.6)$$

In a study reported briefly in the 1960 Annual Report, it was found that a change in atmospheric pressure, Δp_a, of 1 inch of mercury (0.4912 psi) caused a 0.1729 foot change in the water level of Well 153. The specific weight of water, γ, is 0.4335 psi per foot of head. Substituting in equation (6.6)

$$\begin{aligned}\Delta p_w &= 0.4912 + 0.4335\ (-0.1729)\\ &= 0.4162 \text{ psi}\end{aligned}$$

and $\Delta s_c = 0.0750$ psi since $\Delta s_c = -\gamma(h' - h)$.



SYMBOLS

p_a	atmospheric pressure
p_w	hydrostatic pressure
s_c	compressive stress on aquifer
γ	specific weight of water
h	level of water surface from datum point
V_w	volume of water per unit volume of aquifer
E_w	bulk modulus of compression of water
α	porosity of aquifer
V_s	aquifer compression
B	barometric efficiency
β	compressibility of the aquifer
S	storage coefficient
b	aquifer thickness
E_s	modulus of elasticity of the structure of the aquifer

Fig. 19.1.--Log of well 153 and symbols used in analysis of aquifer.

An expression relating barometric efficiency to aquifer and water properties was devised by Jacob (Trans. AGU 21: 574-586, 1940). Consider a column of unit volume extending through a confined aquifer. An increase in atmospheric pressure, Δp_a, will change the column water volume, V_w, by

$$\Delta V_w = -\Delta p_a \, \alpha \, / \, E_w \tag{6.7}$$

where α is the porosity of the aquifer and E_w is the bulk modulus of compressibility of water (about 300,000 psi). Porosity, α, of the material overlying the aquifer is estimated at 5 percent from previous geologic investigations. Then

$$\Delta V_w = -0.4912 \; (0.05) \; / \; 300{,}000$$

or -0.000000082.

The aquifer volume, V_s, within the column will be compressed by an amount

$$\Delta V_s = -\Delta s_c \; / \; E_s \tag{6.8}$$

where E_s is the modulus of elasticity of the structure of the aquifer. The change in water volume balances the aquifer compression so that $\Delta V_w = \Delta V_s$ if the compression of the solid particles forming the aquifer is neglected. Substituting in equation (6.8)

$$-0.000000082 = -0.0750 \; / \; E_s$$

from which E_s = 914,600 psi.

These relations and those of equations (6.3) and (6.6) can be substituted into the barometric efficiency equation

$$B = \gamma \Delta h \; / \; \Delta p_a \tag{6.9}$$

where $\Delta h = h' - h = -\Delta s_c / \gamma$ to get

$$B = \alpha \, E_s \; / \; (\alpha \, E_s + E_w). \tag{6.10}$$

Substituting numerical values,

$$B = 0.05 \; (914{,}600) \; / \; (0.05(914{,}600) + 300{,}000)$$

from which B is 0.1323. This is a constant for the aquifer and is interpreted as a measure of the competence of the overlying confining beds to resist pressure changes. The aquifer of Well 153 has a low barometric efficiency.

The compressibility, β, of the aquifer can be written as

$$\beta = -(\Delta V_w \;/\; \Delta p_w + \Delta V_s \;/\; \Delta s_c) \qquad (6.11)$$

since

$$\beta = -(\partial V/V) \;/\; \partial p \qquad (3.36)$$

where V is volume and p is pressure within a column of unit cross-sectional area extending upward through a confining aquifer. Substituting from equations (6.7) and (6.8),

$$\beta = \alpha/E_w + 1/E_s \qquad (6.12)$$

and from equation (6.10),

$$\beta = \alpha/E_w B. \qquad (6.13)$$

Equation (3.36) may be rewritten in terms of the storage coefficient, S, as

$$\beta = S/\gamma b \qquad (3.37)$$

or

$$S = \beta\gamma b \qquad (6.14)$$

where b is the aquifer thickness. Substituting from equation (6.13),

$$S = \alpha\gamma b \;/\; E_w\, B. \qquad (6.15)$$

Finally, substituting numerical values,

$$S = 0.05\ (0.4335)\ (8.33)\ /\ 300{,}000\ (0.1323)$$

from which S = 0.00000455. For a vertical column 1 foot by 1 foot extending through the aquifer, S equals the volume of water in cubic feet released from the aquifer when the piezometric surface declines 1 foot.

Using basically the same techniques as outlined above, W. B. Caswell, Jr. investigated the barometric efficiency of 5 drilled wells in the vicinity of watershed 118 (The hydrogeology of thin-limestone layers in east-central Ohio, unpublished Ph.D. thesis, the Ohio State Univ., 1969). He

found average barometric efficiencies to vary from 0.46 to 0.58 with confining layers of about 45 feet of shale.

I. <u>COMMENTS AND INTERPRETATIONS</u>: The low value of barometric efficiency in well 153, 0.13, and the relatively high values of 0.46 to 0.58 near watershed 118 are not surprising. The aquicludes of the wells were 4.2 feet and about 45 feet thick respectively. Well 153 is a dug well located close to the aquifer outcrop and any pressure build-up probably bleeds off in seepage to the surface. The cased wells near watershed 118 are at least 500 feet from the outcrop.

Caswell contrasted the hydrologic properties of confined and unconfined areas of this limestone aquifer. Water movement is very slow, perhaps only a few feet per day, where the aquifer is confined, and recharge is very slow due to the thickness and low permeability of the confining layers. Nearer the outcrop, water velocity approaches 400 feet per day and the rate of recharge is relatively rapid.

One of the most interesting numbers from all the arithmetic gyrations may be the value of the storage coefficient. Although numerically small for well 153 ($S = 0.00000455$), the aquifer delivers important quantities of water to streamflow. In calendar year 1963, spring 23 -- a stone's throw away from well 153 -- furnished 212,714 cubic feet of water to the stream channel. This amounted to 1.5 percent of the total flow of nearby watershed 174 for that year accounted for by this one spring.

SWC-011 cCos-1. Volunteer rainfall observers in the 1600 mi^2 area north of the research station furnished summer storm rainfall information on which to define spacial distribution patterns. The June 12, 1970 event was entirely confined to the study area. Rainfall at the center totaled 3.3 inches. Maximum average rainfall depth for 11 mi^2 from field data was 2.7 inches; 1.8 inches fell on 50 mi^2 and 0.6 inches fell on 300 mi^2. The theoretical Gaussian distribution closely matched the field data giving values for comparable areas of 2.8, 2.0, and 0.5 inches, respectively. (Cos-68-11)

The Stanford Streamflow Simulation Model performance was improved by the use of multiple flow recession constants for areas of stratified geology to replace the single recession constant used in Model IV. Further improvement was accomplished by the use of a new snowmelt subroutine that accumulated snow storage when the temperature parameter designated precipitation as snow, and depletion of snow storage release of snowmelt water based on heat balance equations of pure physics plus a few empirical coefficients. In order to improve the model for simulating streamflow for small watersheds of 122 to 1520 acres in size, the model routine time interval was reduced from 15 minutes to 5 and 3 minutes, resulting in: 1) peak flow occurring earlier, 2) synthesized storm flow volumes increasing, 3) baseflow and interflow recession curves decreasing, and 4) no noticeable change in yield and daily flow volumes. (Cos-68-14)

Equations were developed to estimate the frequency of evapotranspiration or potential evapotranspiration for any duration from one day to one month for the growing season in a broad area of the east central United States. (Cos-68-13)

Corn stover residue and manure mulch on no-tillage corn weighing lysimeter reduced evaporation by 3.4 inches in the May - August period. During the period May - July when bare ground was gradually being covered by corn plants, evapotranspiration from the mulch-covered soil was 1 inch per month less than that computed for conventional tillage without mulch. In August, corn plants of both tillage practices covered the soil surface, evaporation was minimal and transpiration was the maximum transport agency of soil water to the atmosphere. ET in August was the same under the two systems. In the drier seasons of 1965, 1966, and 1967 soil water content in the topsoil of the conventional corn watersheds was considerably less than that of no-tillage mulch corn. In 1970, 3.5 inches of rain in each month, May, June, and July replenished much of the water removed by evaporation preventing strong soil water deficiencies from developing under either treatment. (Cos-68-16)

SWC-027 cCos-2. Insecticide (dieldrin) transported in solution by storm runoff from a corn watershed on 15 percent slope in 1 year amounted to 0.07 percent of that applied. This was a maximum value. The minimum value on another watershed, totaled for a 3-year period only 0.007 percent. Maximum concentration of 20 ppb occurred during the 3-month period after application, when corn plants supplied

little protection against rain-drop splash. Concentrations soon thereafter dropped below 5 ppb, and to less than 2 ppb in the second year.

Much more dieldrin was transported by sediment movement in the soil-erosion process. In the 5-month corn season after application, 2.2 percent of that applied was removed by sediment transport -- 30 fold that transported by water. Watershed land in this case was tilled so as to encourage soil erosion. Conservation practices that reduce soil erosion would effectively reduce insecticide pollution of water bodies.

Movement of dieldrin into the air occurs by vaporization from liquid spray application. Pollution of the air in this manner can be reduced by spraying at times of little wind movement and cool temperature. Use of pesticide granules for application is another means of reducing air pollution.

Insecticide (methoxychlor) and herbicide (2,4,5-T) applied to the surface of a grass-covered monolith lysimeter were observed in low concentrations in runoff water and were of no consequence in water percolating to ground-water. Water-soluble 2,4,5-T was first found in percolating water, 8 feet below the ground surface, 9 months after application, at a concentration of 0.5 ppb. Three months later, the concentration had further dropped to 0.1 ppb. No methosychlor moved through the soil to this depth during the 14-month study period.

Average annual N (total) concentration in flow from farmland (1.8 ppm) was 2.2 that of woodland (0.8 ppm). Phosphorus concentration in flow from farmland (0.022 ppm) was 1.5 that from woodland (0.015 ppm).

Average annual N carried by the farmland stream was 4.5 kg/ha and by the woodland stream, 2.4 kg/ha. Concentration in runoff varied little throughout the year. The volume of water flow was the most significant factor in the transport of nutrients. (Cos-C6-12)

Nitrate concentration in flow from a beef cattle barnlot was < 2 ppm for 7 months of the year and peaked at < 10 ppm in September. Nitrate concentrations increased with temperature increases from June through September. Total nitrogen and phosphorus concentrations decreased from January into mid summer.

The quality of runoff water from a beef cattle barnlot changed noticeably as it filtered through 500 m of grass waterway and combined with flow from 30 ha of general farmland. Nitrate nitrogen concentration in flow at the barnlot averaged 1.3 greater than that at the waterway outlet. Total N was 8.3 greater. Phosphorus was 27.9 greater. Phosphorus in the runoff water from the 0.17-ha barnlot was 22 percent of the amount transported from the entire 30 ha watershed. However, the barnlot runoff water transported only 1.2 percent as much nitrate as measured at the waterway outlet.

Keeping all barnlot runoff out of the waterway system for 8 months (May through December 1970), by spreading it onto nearby pasture land, did not improve water quality at the waterway outlet. (Cos-68-18)

Keeping all [illegible] [illegible] out of the waterway [illegible] for 8 months (May through December 19[illegible]) [illegible] pasture land will not improve water quality at the [illegible]. ([illegible] 166-169)

LIST OF PUBLICATIONS

1. Publications

SWC-011 cCos-1

Harrold, L. L. 1970. Evapotranspiration: A factor in the plant-soil-water economy. Proc. First International Seminar for Hydrol. Prof., Univ. Ill., Vol. II, pp. 694-716.

Harrold, L. L. and Dragoun, F. J. 1969. Effect of erosion control land treatment on flow from agricultural watersheds, Trans. Am. Soc. Agric. Engr. 12(6):857-861.

Harrold, L. L. 1970. Representative and experimental basins, an international guide for research and practice. Edited by C. Toebes and V. Ouryvaev (L. L. Harrold a contributor). UNESCO studies and reports in hydrology, No. 4, 348 pp.

Harrold, L. L., Triplett, G. B., and Edwards, W. M. 1970. No-tillage corn -- characteristics of the system. Agric. Engr. 51(3):128-131.

Ricca, V. T., Simmons, P. W., McGuinness, J. L. and Taiganides, E. P. 1970. Influence of land use on runoff from agricultural watersheds. Trans. Am. Soc. Agric. Engr. 13(2):187-190.

SWC-027 cCos-2

Bentz, W. W. and Edwards, W. M. 1970. Automatic equipment for taking large volume samples of runoff water. U. S. Dept. Agric. ARS 41-171, 12 pp.

Edwards, W. M. and Harrold, L. L. 1970. Agricultural pollution of water bodies. Ohio Jo. Sc. 70(1):50-56.

Harrold, L. L. and Edwards, W. M. 1970. Watershed studies of agricultural pollution. OARDC OHIO REPORT 55(4):85-86.

Harrold, L. L. 1971. Preliminary fact sheets on pollution from agriculture in Ohio. Mimeograph - 12 pp.